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An intelligent system for handwriting biometric forgery detection – communication from the research project implementation

Inteligentny system do identyfikacji fałszerstwa cech biometrycznych pisma ręcznego – komunikat z realizacji projektu badawczego

Abstract

The aim of this study is to discuss the main assumptions and goals of the "Rękopis" project, as well as to present the achieved results in the current phase of its implementation. The study is divided into two parts. The first part introduces the issue of handwriting in terms of its biometric properties and evaluates the possibilities of utilizing both classical methods and more advanced technologies in the analysis of original manuscripts to determine the technique of their application to a document surface, either manually or mechanically using a CNC device. In the second part, the applied research procedures and techniques will be presented, along with the obtained results of utilizing the characteristics of handwritten script, with particular emphasis on its biometric properties, in achieving the project goal mentioned above. Project "Rękopis" with the number DOB-SZAFIR/06/A/042/01/2020 titled "Intelligent System for Handwriting Biometric Forgery Detection" is funded by the National Centre for Research and Development (NCBR), within the framework of the SZAFIR program, Competition No. 1/SZAFIR/2020. The project is carried out by a consortium composed of the Central Forensic Laboratory of the Police (leader), the Criminalistics Institute of the Polish Forensic Association Ltd., and JAS Technologies Ltd. The project implementation is planned for 48 months from 2020 to 2024.

Keywords: Handwriting analysis, handwriting imitation on CNC device, handwriting biometric features, artificial intelligence, assessment of original manuscript execution technique.

Streszczenie

Celem niniejszego opracowania jest omówienie głównych założeń i celów projektu „Rękopis" oraz przedstawienie uzyskanych wyników w obecnej fazie jego realizacji. Opracowanie podzielone zostało na dwie części. Pierwsza przybliża problematykę pisma ręcznego w ujęciu jego

właściwości biometrycznych oraz ocenę możliwości wykorzystania zarówno klasycznych metod, jak i bardziej zaawansowanych technologii w badaniach pierwopisów pod kątem określenia techniki ich naniesienia na podłoże dokumentu: ręcznie, czy maszynowo za pomocą urządzenia CNC). W drugiej części zostaną zaprezentowane zastosowane procedury i techniki badawcze oraz uzyskane wyniki wykorzystania cech pisma ręcznego, ze szczególnym uwzględnieniem jego właściwości biometrycznych, w realizacji wskazanego wyżej celu projektu. Projekt „Rękopis" o numerze DOB-SZAFIR/06/A/042/01/2020 pt. „Inteligentny system do identyfikacji fałszerstwa cech biometrycznych pisma ręcznego", jest finansowany ze środków NCBR, w ramach pk. „SZAFIR" z Konkursu nr 1/SZAFIR/2020. Projekt jest realizowany przez konsorcjum w składzie: Centralne Laboratorium Kryminalistyczne Policji (lider), Instytut Kryminalistyki Polskiego Towarzystwa Kryminalistycznego sp. z o.o. oraz JAS technologie sp. z o.o. Realizacja projektu została zaplanowana na 48 miesięcy w latach 2020–2024.

Słowa kluczowe: Ekspertyza pisma, imitacji pisma ręcznego na urządzeniu CNC, cechy biometryczne pisma, sztuczna inteligencja, ocena techniki wykonania pierwopisu.

1. Introduction

For many years, machines (CNC – *Computer Numerical Control*) have been available on the market, allowing for the imitation of handwriting using a writing tool attached to the machine's holder. These computer-controlled machines process data in 3D technology, meaning three-dimensionality (X, Y, Z axes). Control in the X and Y axes enables the precise reproduction of the height and width of writing elements as well as the angles of inclination of these elements (in other words, the graphic parameters of the script). Meanwhile, control in the Z axis involves regulating the pressure of the pen tip on the writing surface. Proper machine programming enables the generation of handwriting-like writing with variable pressure, similar to the imitated handwriting, which allows for forgery with very high precision.

To date, there is no effective method to differentiate between handwritten script and its machine-generated imitation, posing a significant challenge in verification and comparative analysis studies. An even greater challenge lies in assessing whether an individual, anonymous writing is produced by a human hand or by a mechanical device, especially in situations lacking any comparative material. In theory, this could lead to questioning every handwriting expertise. Recognizing the importance of this issue in legal proceedings, a research project called "Rękopis" was developed. Its primary goal is to devise a research method that can determine whether an analysed original manuscript was written by hand or imitated using a mechanical device. The "Rękopis" project is carried out by a scientific-industrial consortium composed of the Central Forensic Laboratory of the Police (project leader), the Criminalistics Institute of the Polish Forensic

Association Ltd., and JAS Technologies Ltd. The project implementation is planned for 48 months from 2020 to 2024[1].

The purpose of this work is to discuss the main assumptions and goals of the "Rękopis" project and present the achieved results in the current phase of its implementation. The study is divided into two parts. The first part introduces the subject of handwriting from the perspective of its biometric properties and evaluates the potential of using both classical methods and more advanced technologies in the analysis of original manuscripts to determine the technique of their application onto a document surface. In the second part, the applied research procedures and techniques will be presented, along with the obtained results of utilizing the characteristics of handwritten script, with particular emphasis on its biometric properties, to achieve the aforementioned project goal.

2. Handwriting as a biometric feature

The project's concept adopts the assumption that handwriting, especially signatures, belongs to biometric characteristics that enable the identification of individuals. Biometric identification can be based on biological-physical and behavioural features that are associated with the human body. In the case of the former, individuals have no control over their formation. Currently, the most commonly used biological-physical features include fingerprints, iris patterns, blood vessel system, and facial geometry. Behavioural characteristics, on the other hand, develop through the repetition of specific behaviours, resulting in the individualization of certain traits. Such characteristics include the way of walking or typing dynamics. The criteria of behavioural characteristics are also met by the way of writing, particularly the signature stroke patterns. Regardless of the type of characteristic, the use of biometric technology assumes that these features should exhibit specific properties, such as:

– universality, meaning that a given feature should be present universally within the studied population;

[1] The publication was developed as part of project No. DOB-SZAFIR/06/A/042/01/2020, entitled *Inteligentny system do identyfikacji fałszerstwa cech biometrycznych pisma ręcznego.* The project is funded by the National Centre for Research and Development (NCBR) and is being carried out under the program named "Rozwój nowoczesnych, przełomowych technologii służących bezpieczeństwu i obronności państwa" pk. „SZAFIR" from Competition No. 1/SZAFIR/2020. The project is being executed between 2021 and 2024 by a consortium consisting of Central Forensic Laboratory of the Police, the Criminalistics Institute of the Polish Forensic Association Ltd., and JAS Technologies Ltd.

- uniqueness, allowing for the differentiation of individuals, achievable only when the compared characteristics possess individual distinctiveness;
- stability of the characteristic over time. The more consistent a feature is, the longer it remains useful in the identification/verification process. In cases where a characteristic undergoes evolutionary changes over time, procedures for refreshing the template should be applied (e.g., handwriting samples, facial geometry). This situation can occur in the case of signatures. For a feature to be utilized in biometric comparison, there should also be a possibility for its rapid and non-invasive acquisition;
- acceptability of the feature, which implies that the approach of the community utilizing the specific trait in the identification/verification process should be analysed beforehand for the feasibility of implementing biometric devices of that particular type[2].

Considering the mentioned properties in the context of handwriting, particularly an individual's signature, it can be observed that with some reservations, they fulfil most of the criteria set for biometric characteristics. First and foremost, a signature possesses universality. The vast majority of the population is capable of creating a signature. Literature indicates that handwriting, including signatures, exhibits individual distinctiveness[3]. However, it's important to note that as a behavioural characteristic, a signature is not equally an individual identifier for everyone. This is determined by the identifying value of the analysed graphical creation, which depends on various factors (such as handwriting maturity, structural complexity and type of signature, naturalness of execution, graphomotor skills, the psycho-physical state of the writer, writing conditions, age, and many other factors). A property of handwriting is not only its distinctiveness compared to the script of other individuals but also, to some extent, its variability within the script of a single person. Handwriting characteristics are not constant, which must be considered when creating a biometric template based on handwriting images[4]. Biometric features of handwriting, as identifiers of the writer, can be used to assess the technique of creating the analysed script – whether it was handwritten or machine-generated. In essence, it’s about determining

[2] M. Tomaszewska-Michalak, *Pismo ręczne jako cecha biometryczna,* cz. I, „Problemy Współczesnej Kryminalistyki”, 2022, Vol. XXVI, p. 425–426.

[3] See: Z. Czeczot, *Badania identyfikacyjne pisma ręcznego*, publ. house Zakł. Krym. KG MO, Warszawa 1972, p. 23–27; A. Feluś, *Podpisy – studium z pismoznawstwa kryminalistycznego*, Uniwersytet Śląski, Katowice 1987; M. Goc, *Współczesny model ekspertyzy pismoznawczej. Wykorzystanie nowych metod i technik badawczych*, 3rd edition, Polskie Towarzystwo Kryminalistyczne, Warszawa 2020, p. 133–135.

[4] M. Tomaszewska-Michalak, *Pismo ręczne…, op.cit.,* p. 426.

whether the distinctive biometric features of handwriting, recorded using appropriate technical tools (primarily profilometers), have undergone any modifications (i.e., forgery through imitation) in the case of machine-generated scripts, which would allow for confirming this fact.

3. Research on the effectiveness of classical methods for handwriting analysis in assessing the technique of applying script to document surfaces

In the initial phase of the project, it was decided to assess the effectiveness of existing solutions used in forensic examinations regarding handwritten entries that have been falsified using a mechanical digital device (CNC). To achieve this, inquiries were made to document experts to conduct tests using available technologies. Each expert received a specific number of signature samples, including initials and short text entries produced by different individuals at a natural pace. These samples were created on two types of paper with different smoothness and weight: 80g/m^2 and 250g/m^2. This also took into account the hardness of the surface (directly on a hard surface and on a surface with three sheets of xerox paper as a cushion), using regular and gel pens, fountain pens, and fine liners with varying ink colour, line thickness, and covering material composition. In the first phase of these tests, experts received individual handwriting samples without information about the execution technique of each sample (handwritten or machine-generated). The research goal was to answer the question:

Is it possible, and if so, how, to determine whether the examined individual handwriting sample in the form of a manuscript was done manually or mechanically using a CNC device?

Subsequently, experts will analyse pairs of samples with identical textual content, of which one was produced by machine and the other by hand. Their task will be to establish:

Is it possible, and if so, how, to differentiate between handwritten original manuscript entries and their machine-generated imitations based on forensic examinations of pairs of entries, with one created by the subject (handwriting) and the other using a CNC device?

The tests have not yet concluded, and the final results will be presented in the subsequent part of the project's progress report.

To facilitate handwriting analysis and standardize the research procedure, experts were provided with a methodological guide along with a questionnaire. The completion of this questionnaire enables a collective analysis and compilation of

results from the conducted expertise. In addition to the filled questionnaire, experts prepare full-text opinions along with visual documentation, which serves as the essential analytical material for project tasks. In total, within the scope of the tests, 30 expertise assessments were conducted in the initial phase, and another 30 are in progress. In accordance with the assumptions, the results of the conducted tests have confirmed the hypothesis of the inability to determine using conventional methods and research techniques whether the analysed individual original samples were handwritten or produced by a machine. No definite conclusions indicating the method of applying the analysed sample to the document were found in any of the opinions based on the tested samples. In approximately 50% of the responses, despite the inability to determine the method of creating the examined script sample, directional indications of the type of writing technique used were provided simultaneously. These include statements such as:

1. *Graphical-comparative examination of the questioned signature, in the form of initials,* ***did not allow for a clear determination of the execution technique of the examined signature*** *(whether it was executed by hand or "machine--generated") – expertise R-2/23.*
2. *Graphical-comparative examination of the questioned signature, which includes personal data for Łukasz D..., demonstrated* ***that it is not possible to determine the technique of applying the signature to the surface****. Characteristics indicating manual execution include indentation, shading of lines, lack of sharpness (except for the letter Ł), finalization, and initiation of character strokes. Characteristics indicating machine-generated execution include the "overlap" of lines in letters a, D, k. – expertise R-3/23.*
3. *[...] examinations using elements of the graphical-comparative method for an illegible single-element signature indicated that it was executed in the original manuscript using a writing instrument such as a ballpoint pen, as evidenced by the material structure typical of ballpoint pen writing (shading of graphical lines, continuity of graphical lines, uneven ink saturation), grooves, reliefs. Furthermore, the natural, well-practiced character of the writing, without signs of artificial writing, such as abrupt stops, which might have distinct characteristics in relation to those done manually, also supports this conclusion.*
   - ***response: non-categorical indication of handwritten sample execution. It is not possible to conclusively determine whether the examined individual handwriting sample in the form of an original manuscript was created manually or machine-generated using a CNC device*** *– expertise R-4/23.*

4. *[...] examinations using elements of the graphic-comparative method of an illegible single-element signature indicated that it was executed in the original version, using a writing instrument of a marker type, as evidenced by its even distribution, flat and non-deep line.*
   - ***response: inability to determine the execution technique of the sample.*** *It cannot be determined whether the examined individual handwriting sample in the form of an original manuscript was created manually or machine-generated using a CNC device – expertise R-6/23.*
5. *Graphical-comparative examination of the questioned signature, in the form of initials,* ***did not allow for a definitive determination of the execution technique of the examined signature (whether it was executed by hand or "machine-generated").*** *It cannot be determined whether the examined individual handwriting sample in the form of an original manuscript was created manually or machine-generated using a CNC device – expertise R-7/23.*
6. *Examinations using elements of the graphical-comparative method for a legible, single-element grapheme indicated that it was executed in the original manuscript using a writing instrument such as a ballpoint pen, as evidenced by the material structure typical of ballpoint pen writing (shading of graphical lines, continuity of graphical lines, white lines), grooves, reliefs. Furthermore, the natural, well-practiced character of the writing, without signs of artificial writing, also supports this conclusion.*
   - ***response: non-categorical indication of handwritten sample execution. It cannot be conclusively determined whether the examined individual handwriting sample in the form of an original manuscript was created manually or machine-generated using a CNC device*** *– expertise R-8.*
7. *As a result of the examinations conducted on the signature with the content "Katarzyna R..." marked as entry A on test card number 6628, it was determined* ***that no characteristics were revealed that would challenge the examined signature as being manually composed*** *– expertise R-10/23.*
8. *[...] examinations using elements of the graphical-comparative method for a legible, single-element grapheme indicated that it was executed in the original manuscript using a writing instrument such as a ballpoint pen, as evidenced by the material structure typical of ballpoint pen writing (shading of graphical lines, continuity of graphical lines, white lines), grooves, reliefs. Furthermore, the natural, well-practiced character of the writing, without signs of artificial writing, also supports this conclusion.*
   - ***response: non-categorical indication of handwritten sample execution*** *– expertise R-16/23.*

9. *Based on the examinations of the evidentiary script with the content "Katarzyna R..." [...] it is determined that:*
   1) *the evidentiary script reflects many characteristics of handwriting executed by hand;*
   2) *the absence of certain characteristics typical of handwriting executed by hand or their weak intensity indicates* ***that the examined script was most likely not directly applied by a human hand;***
   3) *determining whether the examined individual handwriting sample in the form of an original manuscript was created manually or machine-generated using a CNC device would require the expert to familiarize themselves with patterns of samples written by a machine – expertise R-22/23.*

In cases of non-categorical indications of the writing method, their accuracy was low. However, due to the ongoing tests in the described phase of the research project, specific results will be presented in the second part of the study.

4. The assumptions of research methodology based on advanced optical-computer technologies using artificial intelligence

Given the lack of effective methods for assessing the way in which analysed writings are applied to a document (manually or mechanically), the fundamental outcome of the project should therefore be the development of a research methodology based on an optical-information system utilizing artificial intelligence. This methodology aims to enable forensic examinations of handwritten writings (signatures) produced using digital-mechanical CNC devices.

Based on the conducted tests, it has been concluded that the detailed analysis of the structure of the line in the writing should consider graphic features such as:

- distribution of the covering material at points of directional changes in the course of the graphic line;
- profiling (shape, thickness) of the beginnings and endings of lines;
- smoothness of graphic motion in straight and curved elements;
- continuity of the graphic line;
- level and distribution of pressure of the writing tool on the surface;
- direction of writing and the sequence of characters;
- shape of relief and relief profile;
- other symptoms that disrupt the naturalness of line drawing.

As mentioned earlier, writing contains individual (biometric) characteristics of the person executing it, developed and solidified through years of forming graphic habits (including the automation of signature forms). In the case of mechanical

devices, the value of the Z-axis, which is pressure, is determined by the programmer and remains constant over a certain segment. Therefore, detailed analyses of manual handwritten records and corresponding ones produced using a mechanical device should be conducted. These analyses should involve the use of a profilometer along with the Mountains Map software and an electron microscope. The goal is to identify significant differences in their relief profiles and shapes, and to determine an Abbott curve that describes the variation in profile and surface properties as they change with depth. In the current research phase, it has been observed that the relief profile of a machine-generated writing doesn't exhibit as sharp peaks as in the relief of handwritten writing. The peaks are more rounded, but the depth drop is abrupt rather than gradual, as seen in the relief profile of handwritten text[5].

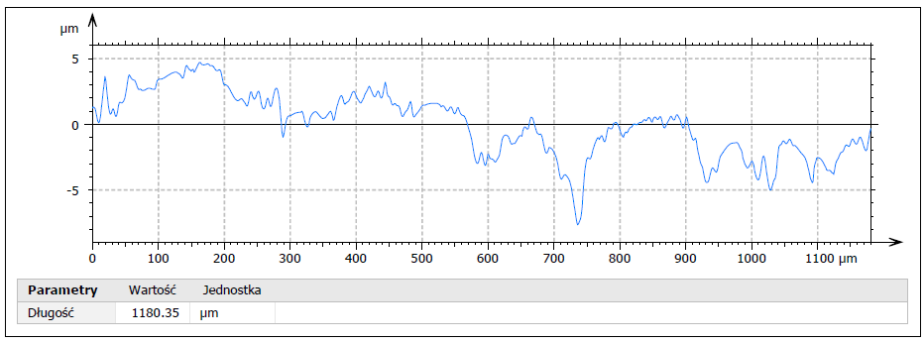

Figure 1. Profile obtained from the relief of handwritten text

Source: U. Konarowska – author's own work.

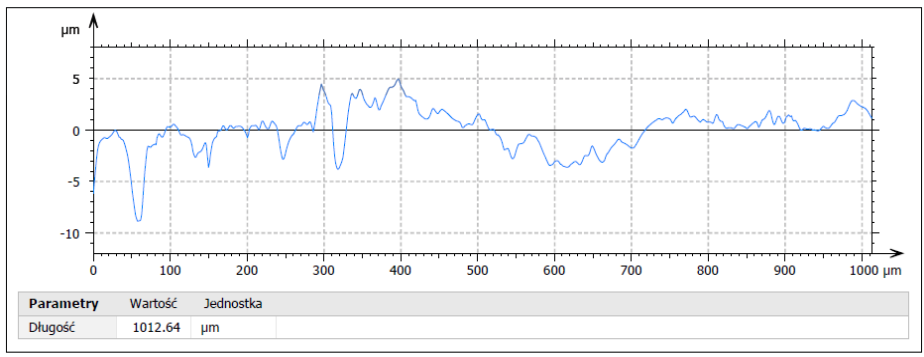

Figure 2. Profile obtained from relief of the inscription made by a machine

Source: U. Konarowska – author's own work.

[5] The research conducted by U. Konarowska at the Criminalistics Institute of the Polish Forensic Association

Also, the distribution of the Abbott curve for handwriting is different from that of the one made by the mechanical device.

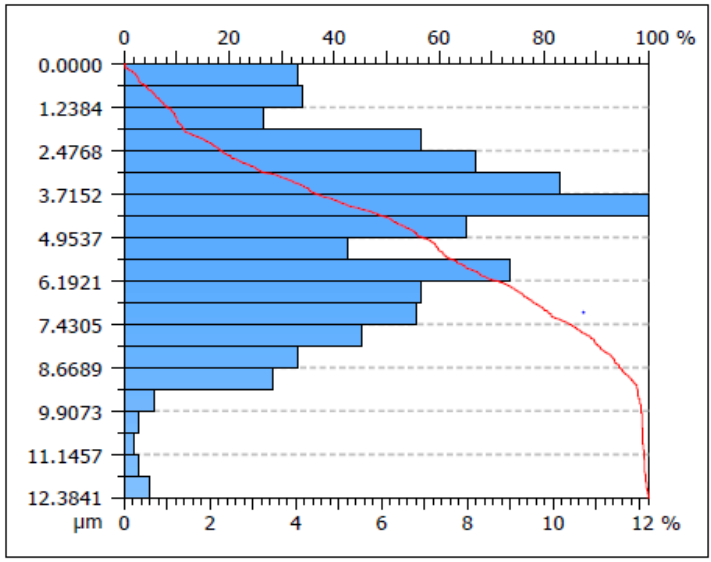

Figure 3. Abbott Curve obtained from the relief of handwriting

Source: U. Konarowska – author's own work.

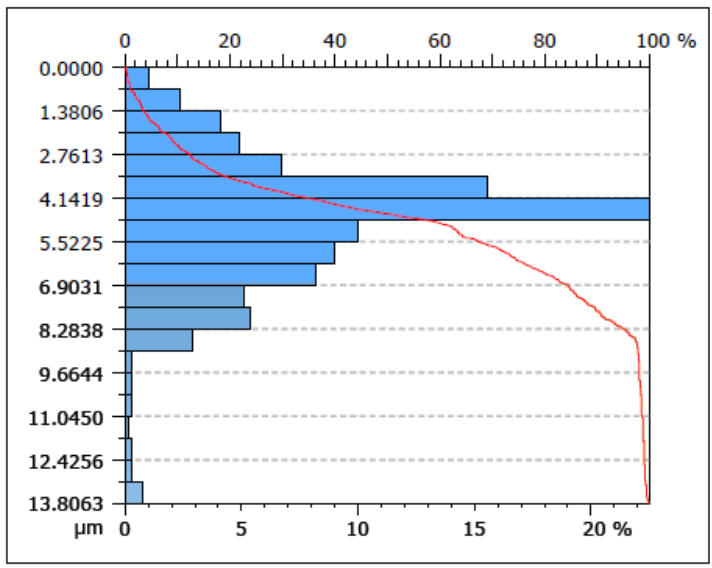

Figure 4. Abbott Curve obtained from the relief of the inscription made by a machine

Source: U. Konarowska – author's own work.

The obtained data from the Mountains Map program, such as the relief profile, depth, and peak heights, can be utilized by an expert for ongoing comparative analysis of the examined writing samples in terms of assessing how they were applied to document surfaces. In binary file format, this data serves as the foundation for an automated authenticity verification system for writing samples (signatures) using artificial intelligence. To achieve this, the project has developed:

- an artificial intelligence algorithm for automatic extraction of handwriting features based on parametric motor skills and pressure data;
- an artificial intelligence algorithm for automated handwriting expertise that operates based on a complete set of features visible in the examined sample as well as prior training data.

These algorithms constitute a crucial component of the handwritten signature authenticity verification module, which, in turn, is part of a larger system designed to support forensic specialists in verifying whether the examined handwriting (represented by a set of features extracted from device-acquired data) is authentic (created by a human) or has been generated by a machine as a forged record. These matters are subject to separate study, in which detailed information on these topics will be presented[6].

Figure 5. Visualization of pressure zones in a fragment of a graphic line (enlarged approximately 10 times)

Source: Krystyn Łuszczuk – author's own work.

As part of the project, an application based on the analysis of centrifugal "scangraphy" is also being tested. This application aims to detect and determine differences in pressure between handwritten and machine-generated forgeries. The application allows for the isolation of pressure zones within the examined graphic

[6] A paper authored by P. Bilski, *Automatyczna weryfikacja autentyczności podpisu odręcznego z wykorzystaniem metod sztucznej inteligencji*, submitted to a conference „Kryminalistyka – Piękna 130-letnia", Kraków 28–30.06.2023.

line (Fig. 1) and provides a numerical characterization for each of these zones. By comparing the size of the pressure zones in the original handwritten sample with corresponding zones in the machine-generated sample, the application should facilitate highlighting differences and verifying the consistency of the samples[7].

Figure 6. Colour and numerical characteristics of pressure zones shown in Figure 1

Source: Krystyn Łuszczuk – author's own work.

The principle of centrifugal scangraphy involves exposing shadows from the centre of the graphical line towards its outer edges, i.e., in the opposite direction to the typical scangraphy used in SCANGRAF and BARWOSKAN programs, which involves gradually shading the graphical line from the outside towards its "centre"[8] based on time and file size. In the centrifugal scangraphy method, pressure zones from the strongest to the weakest, i.e., from the deepest shadow to the

[7] See more broadly: M. Goc, K. Łuszczuk, *Wykorzystanie skangrafii odśrodkowej w badaniach fałszerstw pisma ręcznego wykonanych za pomocą urządzeń CNC,* „Przegląd Policyjny" 2022, No. 4(148), p. 79–92.

[8] More extensively on the topic of the SCANGRAF and BARWOSKAN programs, among others: B. Goc, M. Goc, A. Łuszczuk, K. Łuszczuk, *Programy komputerowe wspomagające ekspertyzę pismoznawczą,* cz. IV: *Scangraf*, „Człowiek i Dokumenty" 2014, No. 33, p. 69–74; A. Łuszczuk, K. Łuszczuk, M. Goc, *Program komputerowy Barwoskan. Analiza binarna w badaniu linii graficznej pisma* [in:] *Współczesna problematyka badań dokumentów*, ed. R. Cieśla, „Prace Naukowe Wydziału Prawa, Administracji i Ekonomii Uniwersytetu Wrocławskiego", Wrocław 2015, p. 153–163.

brightest, become visible "immediately". This allows for the precise extraction of the core of the graphical line with scalable thickness, which can be coloured with a chosen colour.

5. Summary

In conclusion, it was assumed that the use of appropriate computer applications, the utilization of artificial intelligence, and a highly detailed analysis of the structural properties of handwritten lines can enable the differentiation between an original handwritten signature and its machine-generated imitation. The results obtained so far from test and analytical studies, involving around 1000 samples of signatures and short written texts, conducted using advanced optical-microscopic technologies (including devices like profilometers, videospectrocomparators, Raman spectroscopes, digital and analog microscopes with 3D functionality, and electron microscopes), provide real grounds for a successful conclusion of the project. The culmination of this effort will be the development of a research methodology, along with the indication of appropriate procedures and analytical techniques within the scope of the discussed issues.

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